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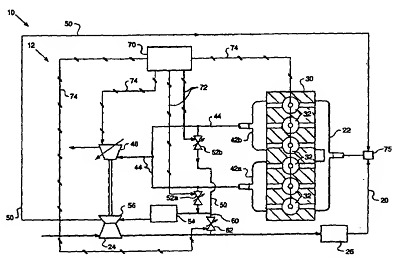
(54) Title: EXHAUST GAS RECIRCULATION SYSTEM



(57) Abstract: A system and method for exhaust gas recirculation (EGR) in a heavy-duty diesel engine (10) is disclosed. The disclosed EGR system (12) comprises an EGR conduit (50), an EGR valve (52a, 52b), an EGR cooler (54), and an EGR driver (56) such as an auxiliary compressor (56) driven by the exhaust gas driven turbine (46) of the engine (10) to forcibly drive the recirculated exhaust gas from the exhaust manifold (42a, 42b) via an EGR conduit (50) to the intake manifold (22) when the EGR valve (52a, 52b) is open. The disclosed EGR system (12) also includes a bypass conduit (60), the flow through which is governed by an electronically controlled bypass valve (62). The EGR system (12) also includes an ECM that controls the bypass valve (62) such that a flow of exhaust gas is directed through the EGR conduit (50) and EGR driver (56) during selected engine operating conditions where the primary EGR valve (52a, 52b) is open (i.e. EGR is on) and directs a flow of intake air from the intake system (24) through the bypass conduit (60) and EGR driver (56) when EGR valve (52a, 52b) is closed (i.e. EGR is off).

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Description

EXHAUST GAS RECIRCULATION SYSTEM

Technical Field

The present invention relates an exhaust gas recirculation (EGR) system and method for use in a heavy duty diesel engine, and more particularly, an EGR system and method that includes a bypass conduit and bypass valve operatively controlled to improve the performance, durability, and reliability of the EGR system.

Background of the Invention

Exhaust gas recirculation (EGR) is a technique commonly used for controlling the generation of undesirable pollutant gases and particulate matter in the operation of internal combustion engines. This technique has proven particularly useful in internal combustion engines used in motor vehicles such as passenger cars, light duty trucks, and other on-road motor equipment. The EGR technique primarily involves the recirculation of exhaust gas by-products from the combustion process into the intake air supply of the internal combustion engine. The exhaust gas reintroduced to the engine cylinders acts to reduce the concentration of oxygen therein, which in turn lowers the maximum combustion temperature within the cylinder and slows the chemical reaction of the combustion process, decreasing the formation of nitrous oxides or NOx.

When utilizing EGR in a turbocharged diesel engine, the exhaust gas to be recirculated is typically removed upstream of the exhaust gas driven turbine associated with the turbocharger. For example, in many EGR applications the exhaust gas is diverted directly from the exhaust manifold and diverted via an EGR conduit to the intake system. Likewise, the recirculated exhaust gas is preferably re-introduced to the intake air stream downstream of the compressor and inter-cooler or air-to-air aftercooler. Reintroducing the exhaust gas downstream of the compressor and intake air cooler device is preferred due to the reliability and maintainability concerns that arise should the exhaust gas be passed through the compressor and/or intake air cooler.

At many engine operating conditions within a turbocharged diesel engine, there is a pressure differential between the intake manifold and the exhaust manifold which essentially prevents many such simple EGR systems from being utilized. For example, at low speed and/or high load operating conditions in a turbocharged engine, the exhaust gas does not readily flow from the exhaust manifold to the intake manifold. Therefore many EGR systems include an EGR driver such as an auxiliary compressor to force the exhaust gas from the exhaust manifold to the higher pressure intake manifold. See European Patent Application No. EP 0 889 226 A2 as well as PCT patent document WO 98/39563 that disclose the use of an auxiliary compressor wheel (or second set of compressor vanes) driven by the exhaust gas driven

turbine associated with the turbocharged diesel engine. The auxiliary compressor wheel forcibly drives the recirculated exhaust gas from the exhaust manifold to the intake system at nearly all engine operating conditions.

One apparent problem with such forced EGR systems that utilize an auxiliary compressor is that the auxiliary compressor requires some flow of air therethrough to minimize the probability of compressor surge condition. A surge condition may cause premature failure to the auxiliary compressor wheel and possibly to the intake air compressor wheel. Thus, when the EGR flow is restricted, many such forced EGR systems are prone to early failure. In other words, the reliability and durability of such conventional EGR systems that utilize such auxiliary compressor is suspect due to the failures attributable to the auxiliary compressor components that are not sized properly to cover all operating conditions, and in particular where EGR is off. What is needed therefor, is a simple and inexpensive improvement to such forced EGR systems that improves the overall EGR system performance while minimizing the likelihood of EGR driver failures. Such an improvement or improved technique should be operable over the entire operating regime or operating conditions for such turbocharged diesel engine. More importantly, what is needed are improvements to such existing EGR systems that provide reliable and durable designs of an EGR system. The present invention is directed at overcoming the problems set forth above.

Disclosure of the Invention

The present invention may be characterized as a system and method for exhaust gas recirculation (EGR) in an internal combustion engine, such as a heavy-duty diesel engine. The disclosed EGR system comprises an EGR conduit extending in flow communication between the exhaust manifold and the intake manifold, an EGR valve disposed proximate the exhaust manifold and adapted for controlling (e.g. on/off) the exhaust gas flow through the EGR conduit. The EGR system also includes an EGR driver disposed along the EGR conduit, the EGR driver being adapted for forcibly driving the recirculated exhaust gas from the exhaust manifold to the intake manifold when the EGR valve is open. The EGR system also includes a bypass conduit and a bypass valve in flow communication with the EGR conduit in a manner that directs intake air through the EGR driver when the EGR is off. In the disclosed EGR system, the EGR driver is an auxiliary compressor driven by the exhaust gas driven turbine such as the embodiments described in European Patent Application No. EP 0 889 226 A2 as well as PCT patent document WO 98/39563.

The present invention may also be characterized as a method for controlling an EGR system similar to the above-described EGR system. In the disclosed method, the EGR system would preferably include an engine control module (ECM) that is adapted to control various flows through the EGR system, and in particular, the ECM controls the bypass valve such that a flow of exhaust gas is directed through the EGR

conduit and EGR driver during selected engine operating conditions where the primary EGR valve is open (i.e. EGR is on). Conversely, the ECM controls the bypass valve such that a flow of air from the intake system is directed through the bypass conduit and the auxiliary compressor during selected engine operating conditions where the EGR valve is closed.

Finally, the present invention may be characterized as an improvement to known EGR systems that utilize an EGR driver means, and in particular, an auxiliary compressor driven by the exhaust gas driven turbine of the engine. As an EGR improvement apparatus, the invention comprises a bypass conduit coupling the intake system with said exhaust gas recirculation conduit at a location upstream of said auxiliary compressor; and a bypass valve disposed along the bypass conduit and adapted for controlling the flow of intake air through the EGR system, including the auxiliary compressor and EGR cooler. The bypass conduit connects the intake system with the EGR conduit upstream of said exhaust gas recirculation cooler and said auxiliary compressor.

Brief Description of the Drawings

The above and other aspects, features and advantages of the present invention will be more apparent from the following more particular description thereof, presented in conjunction with the following drawings, wherein:

FIG. 1 depicts a schematic diagram of an internal combustion engine incorporating the exhaust

gas recirculation system in accordance with the present invention; and

FIG. 2 is a detailed section view of an auxiliary compressor (i.e. EGR driver) employed in an embodiment of the present invention, said auxiliary compressor being integral with a turbocharger.

Preferred Embodiment of the Invention

The following description is of the best mode presently contemplated for carrying out the invention. This description is not to be taken in a limiting sense but is made merely for the purpose of describing the general principals of the invention. The scope and breadth of the invention should be determined with reference to the claims.

Turning to the drawings and particularly Fig. 1, there is shown a schematic diagram of an internal combustion engine 10 having the present EGR system 12. For ease of description, the illustrated engine 10 can be viewed to include four basic systems, namely the intake air system, the main combustion system, the exhaust air system, and an EGR system.

The intake air system of the engine 10 includes an intake air conduit 20, an intake manifold 22, primary intake air pressurizing device (e.g. compressor) 24, and an inter-cooler or an air to air aftercooler 26. The engine 10 also includes a main combustion system that includes, among other elements, an engine block 30 and a cylinder head (not shown) forming a plurality of combustion cylinders therein 32. Although not shown, there is associated with each

of the combustion cylinders: a fuel injector, a cylinder liner, at least one air intake port and corresponding intake valves, at least one exhaust gas port and corresponding exhaust valves, and a reciprocating piston moveable within each combustion cylinder to define, in conjunction with the cylinder liner and cylinder head, the combustion chamber.

The engine 10 also includes an exhaust air system that, as illustrated, includes a split exhaust manifold 42a, 42b, one or more exhaust conduits 44, and an exhaust gas driven variable geometry turbine 46 that drives the primary intake air compressor 24. The illustrated EGR system 12 includes one or more EGR conduits 50, a pair of EGR valves 52a, 52b, an EGR cooler 54, and an EGR driver 56 shown as an auxiliary compressor driven from the exhaust gas driven turbine 46. The illustrated EGR system 12 also includes a bypass conduit 60 and a bypass valve 62.

Finally, the engine 10 includes an engine control module (ECM) 70 for operatively controlling the fuel injection timing, intake air system operation, exhaust air system operation, and EGR system operations, including the control of various engine valves 62, 52a, 52b, and the actuation of the variable geometry turbocharger (VGT) 46 if one is employed. All such engine system controlled operations are governed by the ECM 70 in response to one or more measured or sensed engine operating parameters, which are typically inputs (not shown) to the ECM 70.

As seen in FIG. 1, the EGR system 12 includes one or more EGR conduits 50 extending between

selected locations in the exhaust system and the intake air system. The illustrated EGR system 12 also includes a pair of proportional EGR valves 52a, 52b, each associated with an exhaust manifold 42a, 42b, the twin EGR valves 52a, 52b being positioned (full open, full closed, and various intermediate positions) preferably by a single actuator (not shown) in response to control signals 72 from the ECM 70. The EGR system 12 preferably includes an EGR cooler 54 disposed upstream of an EGR driver as well as an EGR/intake air mixer 75 adapted to re-combine the EGR with the intake air prior to introduction into the intake manifold 22. As is well known in the EGR art, the EGR cooler 54 may include an air to gas cooler, a water to gas cooler or even an oil to gas cooler properly sized to provide the necessary EGR cooling. The EGR driver 56 is represented by an auxiliary compressor device driven by an exhaust gas driven turbine 46 associated with the preferred turbocharged diesel engine. Such EGR driver systems are commonly known and used in various EGR designs.

More importantly, the illustrated EGR system 12 also includes a bypass conduit 60, an on/off bypass valve 62, and an ECM 70 adapted to operatively control the flows through the EGR system 12 by cooperatively controlling the primary EGR valves 52a, 52b together with the bypass valve 62. The bypass conduit 60 is preferably connected in flow communication with the EGR conduit 50 at a first location upstream of the auxiliary compressor 56 or EGR driver 56 and also connected in flow communication with the intake system

at a location downstream of the primary compressor. The illustrated bypass valve 62 is preferably disposed along the bypass conduit 60 so as to provide a flow path between the higher pressure intake system to the low pressure side of the EGR system. As indicated herein, the bypass valve 62 is preferably an electronically controlled on/off valve adapted for controlling flow through the bypass conduit 60 in response to signals 74 from the ECM 70 indicative of selected engine operating conditions.

Although the present EGR system 12 is shown on a four stroke, direct injection, electronically controlled, heavy-duty diesel engine, numerous other engine types, including medium duty diesel engines, light duty diesel engines, alternate fuel engines, two stroke diesel engines, dual fuel engines, etc. are likewise contemplated as suitable engine platforms with which the disclosed invention may be used. In addition, the engine platform may come in a number of different engine configurations including "in-line" and "V" type engines and further having various numbers of cylinders. Furthermore, although the embodiments are shown with split exhaust manifolds, and single actuated, twin EGR valves, numerous other configurations are possible including single manifolds and/or single EGR valve. Likewise, the use of a variable geometry turbocharger can easily be interchanged with other more conventional turbochargers or similar such supercharging devices.

Turning now to FIG. 2, there is shown the details of a turbocharger employing an integral EGR

compressor or auxiliary compressor to which the present invention is directed. As described in PCT document WO 98/39563, the turbine 46 is preferably contained in a cast turbine housing 80 that incorporates a radial exhaust gas inlet 82 feeding a bifurcated volute 84. Exhaust gas flowing through the turbine 46 exits at the turbine outlet 86. The primary shaft 88 is supported by a bearing system that includes journal bearings 90 separated by a spacer 92 and thrust collar 94 with bearing 96 all carried within a center turbocharger housing 98 equipped with lubrication channels 100. The primary air compressor 24 is preferably contained within a cast compressor housing 102 which provides an intake air inlet 104, charge air outlet, a diffuser 108, and a volute 110 for the compressed intake air. The compressor rotor 111 is attached to a rotatable shaft 88 and includes the primary vane set 112 for receiving intake air from the intake air inlet 104 and delivering compressed air to the charge air outlet.

The auxiliary compressor 56 or EGR driver is preferably incorporated into the existing rotor 111 of the turbocharger by adding a second set of vanes (i.e. impeller vanes) 114 to the backside of the compressor rotor 111 or wheel. A scroll inlet 116 provides the exhaust gas for recirculation and separate diffuser 118 carries the pressurized exhaust gas to a volute 120. The scroll inlet 116 or auxiliary compressor inlet, diffuser 118, and volute 120 are preferably incorporated in a casting 122 that replaces the conventional compressor back plate for the

turbocharger. Segregation within the turbocharger of the charge air flow in the primary compressor 24 and the recirculated exhaust gas in the auxiliary compressor 56 is maintained by a baffle 124 which is constrained between the compressor housing 102 and auxiliary compressor casting 122. The auxiliary compressor casting 122 is preferably mounted to the primary compressor housing 102 using a retaining ring 126 and several bolts 128 received in the primary compressor housing 102.

As is well known in the art, it is important to segregate the charge air flow and the EGR flow within the intake system in general and the turbocharger in particular to avoid fouling of the intake air system components, both within the primary compressor 24 and any downstream components such as an aftercooler 26. As seen in FIG. 1, the charge air or intake air flow exiting the primary compressor 24 is fluidically coupled to the EGR system 12 using a bypass conduit 60 connected to the EGR conduit 50 upstream of the auxiliary compressor 56. Flow through the bypass conduit 60 is preferably controlled by bypass valve 62 disposed therein in response to signals from ECM 70.

Industrial Applicability

In operation the above-described EGR system and associated method of controlling such EGR system includes the basic steps of: (a) directing a flow of exhaust gas from the exhaust manifold through the EGR conduit and the EGR driver at a first set of engine

operating conditions when the exhaust gas is to be recirculated to the intake system; and (b) directing a back-flow or bypass flow of intake air through the bypass conduit and the EGR driver at a second set of engine operating conditions when exhaust gas is not to be recirculating from the exhaust manifold to the intake manifold. The above-described first set of engine operating conditions corresponds to selected engine operating conditions where the EGR valve is open (i.e. EGR is on), and the exhaust gas flow through the EGR driver is accomplished by closing the bypass valve thereby restricting any flow through the bypass conduit.

On the other hand, the above-described second set of engine operating conditions corresponds to selected engine operating conditions where the primary EGR valve is closed (i.e. EGR is off). For example, EGR is typically off during heavy transient operation to prevent smoke and particulate matter from being emitted. Likewise, EGR is typically off during engine braking in order to improve engine braking capabilities. Finally, EGR may also be turned off during low load operating conditions to prevent EGR gas condensation and associated corrosive attack on core engine and EGR system components. In such operating conditions the intake air flow or bypass flow through the bypass conduit to the EGR driver is accomplished by opening the bypass valve thereby allowing intake air to loop or recirculate through the EGR driver and always keeping an active flow through the EGR driver. When EGR is off (i.e. shut off at the

primary EGR valves), the bypass valve would remain open to allow flow across the EGR driver and prevent damage when the compressor goes into surge.

From the foregoing, it can be seen that the disclosed invention is an exhaust gas recirculation system for an internal combustion engine that includes a bypass conduit and bypass valve for improving the performance, durability, and reliability of conventional EGR systems. While the invention herein disclosed has been described by means of specific embodiments and processes associated therewith, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention as set forth in the claims.

CLAIMS

1. An exhaust gas recirculation system (12) for a turbocharged engine (10) comprising:

an exhaust gas recirculation conduit (50) fluidically coupling an exhaust manifold (42a,42b) and with an intake system (24) of said engine (10);

an auxiliary compressor (56) in flow communication with said exhaust gas recirculation conduit (50) and adapted for forcibly driving said recirculated exhaust gas from said exhaust manifold (42a,42b) to said intake system (24);

an exhaust gas recirculation valve (52a,52b) disposed along said exhaust gas recirculation conduit (50) upstream of said auxiliary compressor (56) and adapted for controlling flow of recirculated exhaust gas through said exhaust gas recirculation system (12);

a bypass conduit (60) fluidically coupling the intake system (24) with said exhaust gas recirculation conduit (50) at a location upstream of said auxiliary compressor (56); and

a bypass valve (62) disposed along said bypass conduit (60) and adapted for controlling the flow of intake air through said exhaust gas recirculation system (12).

2. The exhaust gas recirculation system (12) of claim 1 wherein said auxiliary compressor (56) is driven by an exhaust gas driven turbine (46).

3. The exhaust gas recirculation system (12) of claim 1 further comprising an engine control module (70) adapted to control flows through said exhaust gas recirculation system (12) in response to various engine operating conditions wherein said bypass valve (62) is an electronically controlled valve having an open position that allows flow through said bypass conduit (60) and a closed position that restricts flow through said bypass conduit (60).

4. The exhaust gas recirculation system (12) of claim 3 wherein said exhaust gas recirculation valve (52a,52b) is an electronically controlled valve having an open position that allows exhaust gas to flow through said exhaust gas recirculation conduit (50) and a closed position that restricts exhaust gas flow through said exhaust gas recirculation conduit (50), and wherein said engine control module (70) is further adapted to control exhaust gas flow through said exhaust gas recirculation system (12) in response to various engine operating conditions.

5. The exhaust gas recirculation system (12) of claim 4 wherein said exhaust gas recirculation bypass valve (62) is oriented in said open position when said exhaust gas recirculation valve (52a,52b) is oriented in said closed position.

6. The exhaust gas recirculation system (12) of claim 1 wherein said bypass conduit (60) connects to said exhaust gas recirculation conduit (50)

downstream of said exhaust gas recirculation valve (52a,52b) and upstream of said auxiliary compressor (56).

7. The exhaust gas recirculation system (12) of claim 1 further comprising an exhaust gas recirculation cooler (54) disposed upstream of said auxiliary compressor (56).

8. The exhaust gas recirculation system (12) of claim 7 wherein said bypass conduit (60) connects to said exhaust gas recirculation conduit (50) upstream of said auxiliary compressor (56).

9. The exhaust gas recirculation system (12) of claim 1 wherein said auxiliary compressor (56) further comprises a second set of vanes (114) on a compressor rotor (111).

10. In an exhaust gas recirculation system (12) for an engine (10) having an intake manifold (22), an exhaust manifold (42a,42b), an exhaust gas recirculation conduit (50), an exhaust gas recirculation cooler (54), an exhaust gas recirculation valve (52a,52b), and an exhaust gas recirculation driver (56), an improvement to said exhaust gas recirculation system (12) comprising:

a bypass conduit (60) fluidically coupling the intake system (24) with said exhaust gas recirculation conduit (50) at a location upstream of said auxiliary compressor (56); and

a bypass valve (62) disposed along said bypass conduit (60) and adapted for controlling the flow of intake air through said exhaust gas recirculation system (12).

11. The improvement of claim 10 wherein said exhaust gas recirculation driver (56) is an auxiliary compressor (56) driven by an exhaust gas driven turbine (46).

12. The improvement of claim 11 wherein said auxiliary compressor (56) further comprises a second set of vanes (114) on a compressor rotor (111).

13. The improvement of claim 10 further comprising an engine control module (70) adapted to control flows through said exhaust gas recirculation system (12) in response to various engine operating conditions and wherein said bypass valve (62) is an electronically controlled valve having a first position that allows intake air flow through said bypass conduit (60) to said exhaust gas recirculation system (12) and a second position that restricts intake air flow through said bypass conduit (60).

14. The improvement of claim 13 wherein said bypass valve (62) is oriented in said first position when said exhaust gas recirculation flow is off.

15. The improvement of claim 11 further comprising an exhaust gas recirculation cooler (54) disposed upstream of said auxiliary compressor (56).

16. The improvement of claim 15 wherein said bypass conduit (60) connects to said intake system (24) with said exhaust gas recirculation conduit (50) upstream of said exhaust gas recirculation cooler (54) and said auxiliary compressor (56).

17. A method of controlling an exhaust gas recirculation system (12) of an internal combustion engine (10) having an intake manifold (22), an exhaust manifold (42a,42b), an exhaust gas recirculation conduit (50), an exhaust gas recirculation valve (52a,52b), and an exhaust gas recirculation driver (56), said method comprising the steps of:

directing a flow of exhaust gas through said exhaust gas recirculation conduit (50) and said exhaust gas recirculation driver (56) at a first set of engine operating conditions when said exhaust gas is recirculated from said exhaust manifold (42a,42b) to said intake manifold (22); and

directing a flow of intake air through a bypass conduit (60) and said exhaust gas recirculation driver (56) at a second set of engine operating conditions when said exhaust gas is not recirculating from said exhaust manifold (42a,42b) to said intake manifold, said bypass conduit (60) being disposed in flow communication with said exhaust gas recirculation conduit (50) at a first location upstream of said

exhaust gas recirculation driver (56) and in flow communication with said intake system (24).

18. The method of claim 17 wherein said first set of engine operating conditions corresponds to engine operating conditions where said exhaust gas recirculation valve (52a,52b) is open.

19. The method of claim 17 wherein said second set of engine operating conditions corresponds to engine operating conditions where said exhaust gas recirculation valve (52a,52b) is closed.

20. The method of claim 17 wherein said step of further comprises opening a bypass valve (62) disposed along said bypass conduit (60), said bypass valve (62) being responsive to an engine control module (70) and adapted for controlling the flow of intake air through said exhaust gas recirculation driver (56).

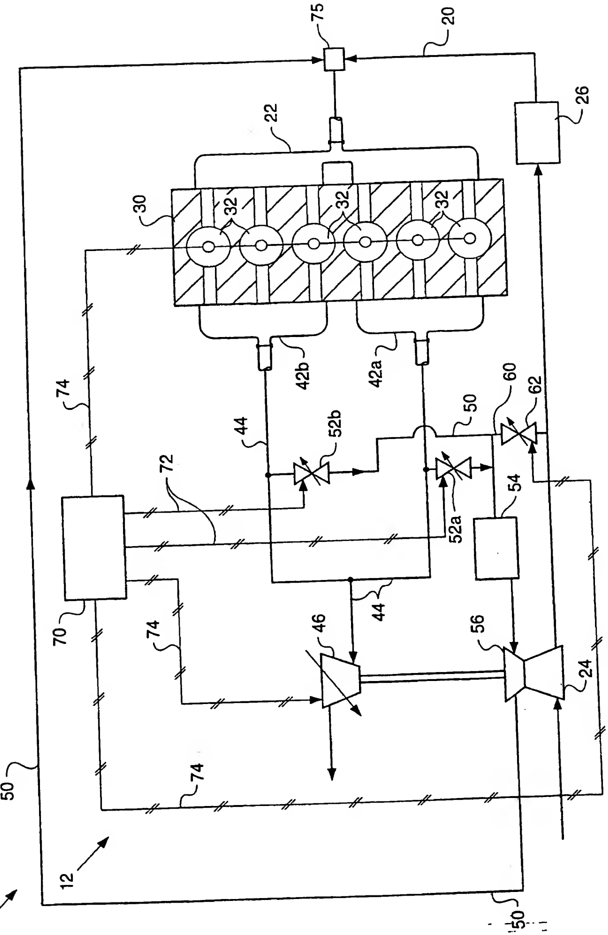
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FIG-1-

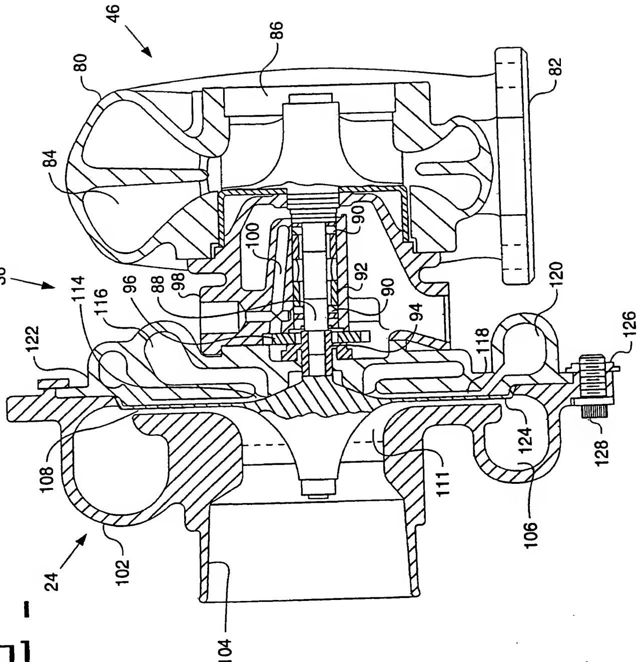
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FIG-2

INTERNATIONAL SEARCH REPORT

Intt ional Application No
PCT/US 00/16118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F02M25/07

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F02M F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2000	04/10/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

information on patent family members

Intı Jonal Application No
PCT/US 00/16118

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